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The Spacewatch program discovers small bodies (asteroids and comets) in the solar system and analyzes their distributions with orbital parameters and absolute magnitude. Scanning of the night sky is conducted with a charge-coupled device (CCD) imaging detector 18-20 nights per month with the 0.9-m Spacewatch Telescope on Kitt Peak. About 1200 to 2000 square degrees of sky are searched each year to a V magnitude limit of 21.5. Spacewatch discoveries support studies of the Centaur, Trojan, Main-Belt, and Earth-approaching asteroid populations. These studies provide information about the evolution of these objects and their orbits. Spacewatch also finds potential targets for space missions, finds objects that might present a hazard of impact on the Earth, provides accurate astrometry of about 30,000 asteroids annually, and does high-priority recoveries of comets and asteroids that are too faint for most other observers. More than 15,000 newly-observed asteroids have received provisional designations from the Minor Planet Center in Cambridge, Massachusetts as a result of incidental astrometry derived from Spacewatch scans. A new telescope of diameter 1.8 meters has been constructed to extend the Spacewatch survey of the solar system to a fainter limit.

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Tom Gehrels Nov. 7, 1997

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ABSTRACT

The Spacewatch program discovers small bodies (asteroids and comets) in the solar system and analyzes their distributions with orbital parameters and absolute magnitude. Scanning of the night sky is conducted with a charge-coupled device (CCD) imaging detector 18-20 nights per month with the 0.9-m Spacewatch Telescope on Kitt Peak. About 1200 to 2000 square degrees of sky are searched each year to a V magnitude limit of 21.5. Spacewatch discoveries support studies of the Centaur, Trojan, Main-Belt, and Earth-approaching asteroid populations. These studies provide information about the evolution of these objects and their orbits. Spacewatch also finds potential targets for space missions, finds objects that might present a hazard of impact on the Earth, provides accurate astrometry of about 30,000 asteroids annually, and does high-priority recoveries of comets and asteroids that are too faint for most other observers. More than 15,000 newly-observed asteroids have received provisional designations from the Minor Planet Center in Cambridge, Massachusetts as a result of incidental astrometry derived from Spacewatch scans. A new telescope of diameter 1.8 meters has been constructed to extend the Spacewatch survey of the solar system to a fainter limit.

Participating Professionals (all at the Lunar and Planetary Laboratory):

Terrence H. Bressi	Electronic Technician
Robert Jedicke	Principal Research Specialist
Jeffrey A. Larsen	Research Associate
Robert S. McMillan	Associate Research Scientist
Joseph L. Montani	Senior Research Specialist
Marcus L. Perry	Staff Engineer
James V. Scotti	Senior Research Specialist

ACCOMPLISHMENTS

Earth-Approaching Asteroids: Spacewatch discoveries of objects in near-Earth space during the period of this grant are summarized by the following Table, in which H designates absolute visual magnitude and "VFMO" stands for "very fast moving object", usually a very small asteroid approaching close to Earth. Objects with $H < 18.3$ are greater than 1 km in diameter, the size generally held to be hazardous to civilization if impacted upon the Earth.

1994	$H<18.3$	$18.3\leq H<23.3$	$H\geq 23.3$	Total
Apollo	5	6	6	17
Amor	1	6	1	8
Aten	0	0	1	1
Total	6	12	8	26

1995	$H<18.3$	$18.3\leq H<23.3$	$H\geq 23.3$	Total
Apollo	4	5	5	14
Amor	3	8	2	13
Aten	0	1	0	1
Total	7	14	7	28

1996	$H<18.3$	$18.3\leq H<23.3$	$H\geq 23.3$	Total
Apollo	2	12	3(+3*)	17(+3*)
Amor	2	7	1	10
Aten	0	0	2	2
Total	4	19	6(+3*)	29(+3*)

(*) 3 VFMOs that came by too fast to be followed and that were therefore not designated by the Minor Planet Center.

1997 (through October)

Apollo	1	4	3	8
Amor	4	2	0	6
Aten	0	0	0	0
Total	5	6	3	14

Overall Total (1989 November - 1997 October)

Apollo	21	35	31(+3*)	87(+3*)
Amor	15	36	8	59
Aten	0	3	4	7
Total	36	74	43(+3*)	153(+3*)

Since former Spacewatch team member David Rabinowitz published his paper entitled "the Size Distribution of the Earth-Approaching Asteroids" (1993 *Ap.J.* **407,** 412-427) based on Spacewatch data through 1991, we have improved sensitivity more than a magnitude and accumulated seven times as many Earth-approachers. Jedicke's debiasing technique is also a better tool to extract the true distribution of these objects versus absolute magnitude, so a revision of that statistic is due.

Impact Hazard: Spacewatch discoveries of Earth-approaching objects contribute to the assessment of the impact hazard. This problem is studied in detail in the book *Hazards due to Comets and Asteroids* (Gehrels, ed. 1994). Spacewatch complements other surveys that have wider area coverage at brighter magnitude, by exploring the hazards of objects down to a diameter of 200 m ($H > 22$) that approach within 0.05 AU of the Earth's orbit.

Recoveries of Mission Targets: Spacewatch recovered both of the potential (now former) targets suggested in 1996 for the Clementine II mission for which better orbits were needed (1987 OA and 1989 UR). 1987 OA was recovered on 1996 June 15 UT (MPEC 1996-M01); 1989 UR was recovered on 1997 Oct 09 UT (MPEC 1997-T06). Neither of these objects was easy to find, partly because neither had been observed since their discovery apparitions. Coincidentally, both had discovery arcs of only 34 days. When recovered last year, 1987 OA was -1.69 degrees off in right ascension and -0.14 deg off in declination compared to the prediction, which corresponds to +3.44 days displacement along its line of variation. 1989 UR was 1.15 deg in RA and -0.55 deg in dec. off from the prediction, corresponding to an ephemeris error of -1.3 days. The recovery of 1987 OA was further hindered by its position low in the sky and in the Milky Way; 1989 UR was harder to find because it was two magnitudes fainter than expected.

Comets: Since 1989, Spacewatch has discovered 11 comets, recovered about 60 comets, and rediscovered one comet. To date in 1997 Spacewatch has discovered six comets.

Main Belt Asteroids: Jedicke and Metcalfe completed a study of the magnitude-frequency relations for three distance zones in the asteroid belt (Jedicke and Metcalfe 1997). The absolute magnitude distribution shows features that provide clues to the type of processing of asteroids by collisions. Their de-biasing technique has also been made available to Tim Spahr at the University of Florida for his dissertation on main-belt statistics (with Prof. S. F. Dermott). Spahr and Jedicke have applied these techniques together to derive the completion of the Palomar-Leiden Survey, which is about 96% over the apparent-magnitude range 16-19.

Centaurs: Spacewatch found its fourth new Centaur asteroid (the 7th overall) early in 1997. In their analysis of Spacewatch data, Jedicke and Herron (1997) found that the Centaurs, which move in orbits approximately between those of Saturn and Neptune, may have a population about as great as that of the main-belt asteroids.

Techniques and Data Analysis: In 1995 a new observing strategy was introduced, in which the regions scanned by the first observer of each run are repeated by the second and third observers. Astrometry of many of the slow moving objects is thereby obtained at three epochs with intervals of between 5 and 9 days, varying according to weather. This adds much sensitivity to main belt and Trans-Neptunian Object (TNO) searches, since the times between the observations are increased by two orders of magnitude compared to three scans spanning only 1.5 hours.

Jedicke and recent UA undergraduate T. S. Metcalfe completed a bias calculation for Spacewatch data - the first ever model-independent bias calculation for asteroid surveys (Metcalfe and Jedicke 1996). This research required characterizing the limiting magnitude, asteroid detection efficiency, losses due to trailing of the object's image during an exposure, and other bias inducing factors. Metcalfe also confirmed that the pre-coma-corrected Spacewatch calibration system was excellent (within 0.01 magnitudes of accepted stellar standards), found a correction associated with the reported magnitudes for saturated stellar images, and confirmed the post-coma-corrector magnitude system.

New Research Associate Jeffrey A. Larsen has been developing better software to detect moving objects. In recorded data being used for testing he has found 40% more asteroids than the software currently in use on Kitt Peak found in the same data.

Hardware at the 0.9-m Telescope: In 1995 a coma corrector was installed on the 0.9-m Spacewatch Telescope. This lens assembly eliminates coma and flattens the focal plane without distorting the field of view. Image quality became uniform across the field and the star images became more centrally concentrated, resulting in another half magnitude of sensitivity. The primary mirror was realuminized in 1995 and 1996 and the collimation of the telescope was improved in 1996. In 1997 the primary mirror was simply washed instead of being realuminized, with satisfactory results. New lightning surge protectors were

installed at the 0.9-m telescope after a nearly direct hit damaged the old surge protectors plus some computer equipment in July 1996. Repairs were made promptly by Spacewatch personnel. Some observing time was lost in late October 1997 due to problems with an interface between our computers and with the telescope drive system. Repairs were effected by Spacewatch personnel, but this system is aging, making a replacement an increasing priority.

New Telescope and Building: Fabrication and installation of the 1.8-m Spacewatch telescope and the construction of its building were completed (Perry *et al.* 1996). Considerable savings in operating costs will be accumulated because the telescope is so close to the facilities and support of the Steward Observatory and the National Optical Astronomical Observatory (NOAO). A dedication ceremony was held at the site on 7 June 1997 and attended by scientists from as far away as Japan and France, as well as by Dr. Charles Holland of the AFOSR. Dr. Holland gave a speech in which he expressed satisfaction that the AFOSR had contributed to the completion of the new telescope. This will be the largest telescope in the world dedicated full time to the search for previously unknown members of the solar system. Its 1.8-m aperture, sensitive CCD, and dedication to surveying will extend all of Spacewatch's exploration of the solar system to exciting new limits.

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